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Prospects for secure and sustainable electricity supply for Pakistan

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Abstract

Fossil fuel reserves are diminishing rapidly across the world, intensifying the stress on existing reserves day-by-day due to increased demand. Not only that, fossil fuels, presently contributing to 80% of world primary energy, are inflicting enormous impacts on environment. Energy sector has a key role in this regard since energy during its production, distribution and consumption is responsible for producing environmentally harmful substances. There is an urgent need for a quicker switch over of energy systems from conventional to renewables that are sustainable and can meet the present and projected world energy demand. Hydrogen, in the capacity of energy vector and storage medium is expected to be the optimum solution for intermittency and storage of energy produced by renewables. Within the context of Pakistan solar and wind power are two of the most promising renewables.

In this article, the current energy consumption for Pakistan is presented and the issue of security of electrical energy supply is discussed. Furthermore, the prospects for a large-scale switch over to renewables are also addressed and the relevant economies and underpinning rationale provided. It has been found that solar energy is a much more economical choice for Pakistan as compared to wind energy-respective costs for solar and wind energy are (US cents/kWh) 20 and 77. This is due to the fact barring the four monsoon months, the average wind speed for the remaining 8 months does not cross an economic threshold. On the contrary, it was found that solar energy has a fairly stable and consistent availability.

Keywords: Sustainability; Renewables; Solar energy; Wind power; Photovoltaic; Hydrogen

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Contents

1. Introduction

Energy is an essential component for continued human development and economic growth. Providing adequate, affordable energy is essential for eradicating poverty, improving human welfare, and raising living standards worldwide. Historically, fossil fuels have been the main source of energy supply and have served the human energy needs for thousands of years. Renewable energy sources have also been important for humans since the beginning of civilisation. Biomass, for example, has been used for heating, cooking and steam production- and hydropower and wind energy, for transport and later for electricity production.

The present energy situation, led by fossil fuels, has three major concerns—depletion of resources, environmental impacts and security of energy supply. During energy use, varied stresses are created on the natural environment, some of which have global implications like the global warming while others cause local impacts such as their effect on human health and ecology. Coal exploration and mining causes land degradation through subsidence and mine fires. The impact of mining on forest areas is of particular concern. Similarly, with onshore oil and gas production drilling waste fluids, drilling waste solids, produced water and volatile organics exhibit the potential to contaminate surrounding water bodies. Nuclear power also has serious reservations due to its associated radioactive emissions. Furthermore, of late nuclear energy use within the third world has come into sharp focus due to its possible association with military uses of nuclear fuel. Renewable energy sources, being clean and environmentally friendly, have a clear edge over the rest of energy systems.

At present fossil fuels are still the most important sources of world's primary energy supply. Fossil fuel reserves, however, are diminishing rapidly across the world. Stress on existing reserves is increasing day-by-day due to increased demand. It was reported in year 2003, that reserve to production ratio of fossil fuels for North America, Europe and Eurasia, and Asia Pacific were 10, 57 and 40 years, respectively [1]. Diminishing reserves of fossil fuels and environmental concerns associated with both fossil fuels and nuclear power are beginning to drive the energy sector worldwide to strive towards renewable energy sources. Renewable energy sources (including biomass, solar, wind, geothermal, and hydropower) that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. They have been acknowledged as a vital and plentiful source of energy that can indeed meet entire world's energy demand. Renewable energy sector at present is meeting 13.5% of the global energy demand [2]. This sector is now growing faster than the growth in overall energy market. Some long-term scenarios postulate a rapidly increasing share of renewable technologies (made up of solar, wind, geothermal, modern biomass, as well as the more traditional hydro). Under these scenarios, renewables could reach up to 50% of the total share of mid-21st century with appropriate policies and new technology developments.

The transition of world energy system to hydrogen as a fuel vector is quite logical and becomes clearer when one takes a look at historical energy production sequence. Each successive transition from one source to another—from wood to coal, from coal to oil—has entailed a shift to fuels that were not only harnessed and transported more economically, but also had a lower carbon content and higher hydrogen content. It is also evident that at each step greater energy density is being achieved. The third wave of decarbonisation is now at its threshold, with natural gas use growing fastest, in terms of use, among the fossil fuels. The fourth wave, the production and use of pure hydrogen, is certainly on the horizon. Its major drivers are technological advances, renewed concern about the security and price of oil and gasoline, and growing pressure to address local air pollution and climate change.

This work presents the current energy scene for Pakistan in terms of its total energy demand and supply, and future challenges. Issues associated with security of energy supply have been studied with respect to recent incidences of interruption to supply of gas. Solar and wind energy prospects have been compared in terms of their present economics.

2. Socio-economics of Pakistan

Availability of energy in any country has a strong relationship with its economic and social stability. The per capita energy consumption is an index used to measure the prosperity of any society. Pakistan is basically an energy deficient country. Pakistan's per capita energy consumption, 3894 kWh as against the world average of 17620 kWh, gives it a ranking of 100 amongst the nations of the world [2]. Pakistan with a population of about 140 million that is expected to rise to 210 million by 2025 is the eighth most populous country in the world [3]. Pakistan has four provinces, the Punjab, the North West Frontier Province (NWFP), Sindh, Balochistan, and two federally administrated territories: the Federally Administered Tribal Areas (FATA) and the Northern Areas. In addition, the territory of Azad Jammu and Kashmir (AJK), is under the administration of the Government of Pakistan. During the last 40 years, Pakistan's economy has grown at an average annual rate of 7.2%. However, due to high population growth rate, per capita

Gross Domestic Product (GDP) has increased at only 4.3% per annum during the same period [4]. Pakistan's per capita GDP is US$2100 while the three main sectors; industry, agriculture and services constitute a GDP share of 26.6, 25.2 and 48.2%, respectively. Main industries include textiles, and apparel, food processing, beverages, construction materials, paper products, fertilizer and other agricultural products [5,6].

Pakistan lies in southern Asia, bordering the Arabian Sea, between India on the east and Iran and Afghanistan on the west and China in the north. Pakistan lies between 23.8 and 36.7 degrees North latitude and 61.1 and 75.8 degrees East longitude, and has a total area of 803, 940 km^2 of which 97% is land area while rest is covered by water. The country is characterized by significant variations in altitude and topography across its territory. Pakistan's diversity extends to its climatic, socio-economic, and environmental characteristics, which differ significantly from region to region. Pakistan's coastline with the Arabian Sea stretches to over 990 km [6,7].

3. The Pakistan energy scene

3.1. Energy demand and supply

Pakistan's commercially exploitable energy resources consist of coal, gas, oil, hydropower, nuclear power and a large base of traditional fuels in the form of fuel wood, agricultural and animal wastes. An analysis of Pakistan's energy supply market indicates that the country is a net importer of energy. The current energy supply matrix is a composite of various technologies. Oil and gas form the bulk of primary commercial energy supply mix of Pakistan, contributing 82.5% (oil: 38.3%, gas: 43.8%, LPG: 0.4%,) as shown in Fig. 1. The other sources include; coal: 5.4%, hydro electricity: 11.3% and nuclear electricity: 0.9%. Pakistan's internal oil production meets approximately one-sixth of the country's current oil requirements. Almost one-third of the country's total energy requirements are met through imports [8]. Fig. 2 shows a Sankey diagram for the energy matrix of Pakistan for the year 2003 [9].

Historically, the country has been dependent on oil imports. The crude oil import for the year 2002–2003 was about 7.1 million tonnes. This account for an equivalent of USD 1.4 billion and that of petroleum products import was 8.4 million tonnes an equivalent of USD

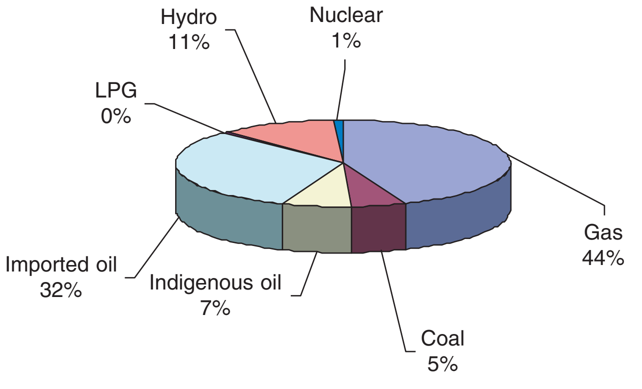


Fig. 1. Overview of primary energy market for Pakistan, 2003–2004.

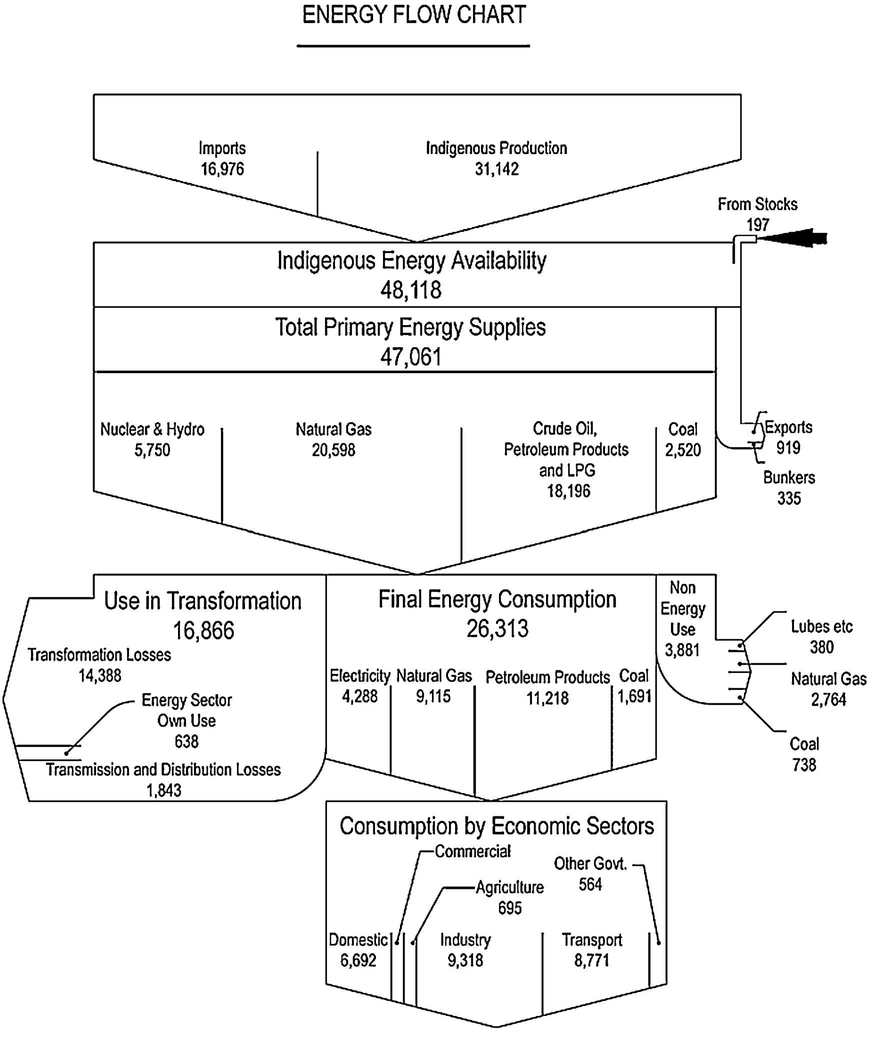


Fig. 2. Energy flow chart of Pakistan, 2003.

1.7 billion. The total annual import bill for the year 2002–2003 accounted for 25 per cent of the total imports. Pakistan's primary energy supplies for the year 2002–2003 amounted to 47.1 million tonnes of oil equivalent (TOE) [8].

The total installed capacity of electricity generation stood at 19,478 MW in 2003–2004 as against 17,776 MW during the previous year, showing a significant increase of 9.6%. The number of electricity consumers has increased due to rapid urbanization, extension of electricity grid supply to un-electrified areas and village electrification. The number of consumers has increased from 8.2 to 13.9 million from 1992–1993 to 2003–2004 registering a growth of 70% in the last 13 years as indicated in Fig. 3 [10]. As per Pakistan Economic Survey 2003–2004, the household sector has been the largest consumer of electricity accounting for 44.2 per cent of total electricity consumption followed by industries

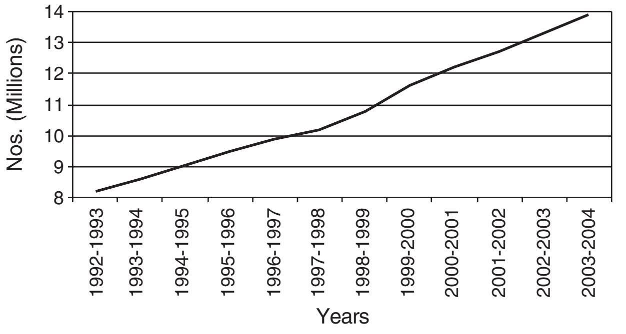


Fig. 3. Growth in number of electricity consumers.

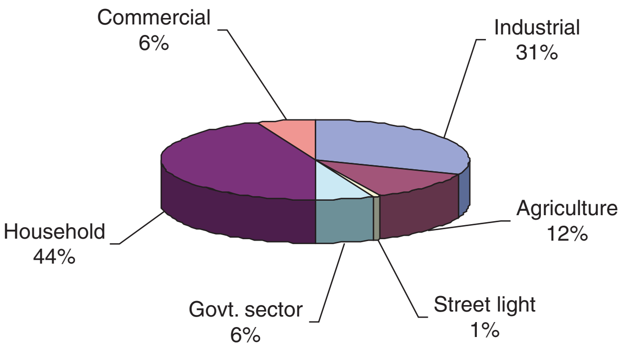


Fig. 4. Sectoral energy consumption for Pakistan, 2003–2004.

31.1 per cent, agriculture 14.3 per cent, other government sector 7.4 per cent, commercial 5.5 per cent and street light 0.7 per cent as indicated in Fig. 4 [11].

Pakistan's energy demand far exceeds its indigenous supplies. Pakistan like other developing countries is energy deficient—the demand for primary energy in Pakistan has increased considerably over the last few decades and the country is facing serious energy shortage problems. The energy supply is not increasing by any means to cope with the rising energy demands. As a result the gap between the energy demand and supply is growing every year. Historically in Pakistan, the growth rate of energy consumption has been significantly higher than the economic growth rate. Fig. 5 shows a rapid increase in per capita energy consumption in Pakistan. Hence if the socio-economic development goals envisaging some 7% per annum growth in the coming decades are to be met and historical trends continue then energy consumption will continue to increase quite rapidly. Other estimates indicate that the energy demand in Pakistan is likely to increase three-fold by the year 2050. The conventional energy sources, oil, gas and coal are limited-oil and gas reserves are left only for 20 and 12 years, respectively, as shown in Fig. 6. The situation with hydropower is not very encouraging either. Since 1997 Pakistan is facing a severe shortage of water due to a cycle of drought and reduced capacity of the country's two major reservoirs, Tarbela and Mangla.

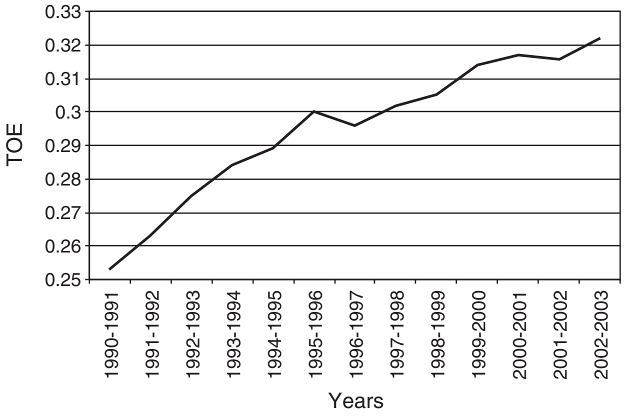


Fig. 5. Per capita energy consumption for Pakistan.

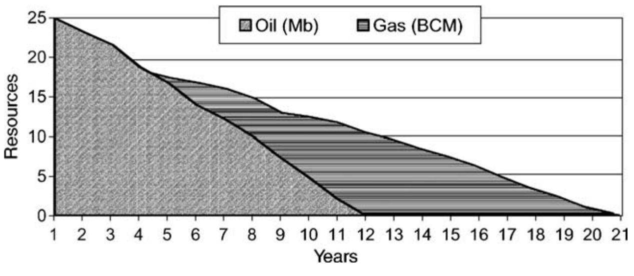


Fig. 6. Projected oil and gas reserves in Pakistan, 2002.

3.1.1. *Oil*

Pakistan has an interesting geo-dynamic history of large and prospective basin (onshore and offshore) with sedimentary area of $827,268\,km^2$. The density of exploration is very low of about one well for over $1446\,km^2$ basin area. So far about 778 million barrels crude oil reserves have been discovered of which 489 million barrels have already been produced. So far over 572 exploratory wells have been drilled by national and international exploration and production companies, resulting in over 154 oil and gas discoveries. Indigenous production of crude oil during the year 2002–2003 was 64,268 barrels per day. This production level meets only 17% of countries oil requirements and 83% is imported. Sectoral oil consumption during the year 2002–2003 was: Power (36.6%), transport (49.1%), agriculture (1.2%), industry (9.8%), domestic (1.7%) and government (1.6%) [8].

3.1.2. *Natural gas*

Pakistan is among the most gas dependent economies of the world. Natural gas was first discovered in 1952 at Sui in Balochistan province which proved a most significant and largest gas reservoir. After successful exploration and extraction, it was brought to service in 1955. This major discovery at Sui followed a number of medium and small size gas fields in other part of the country. So far about 1.2 trillion cubic metre of gas reserves have been discovered of which 453 billion cubic metre have already been produced. Natural gas production during 2002–2003 was about 76 million cubic metre per day. Pakistan has

integrated infrastructure of transporting, distributing and utilizing natural gas with 8200 km transmission and 59,183 km of distribution and service lines network developed progressively over 50 years. Natural gas sectoral consumption during 2002–2003 was: power (38.5%), fertilizer (20.7%), cement industry (0.4%), general industry (18.9%), domestic (17.6%), commercial (2.6%) and Transport (CNG; 1.3%) [8].

Pakistan's demand for natural gas is expected to rise substantially in the next few years, with an increase of roughly 50% by 2006. Pakistan also plans to use gas for future electric power generation projects, hoping to substitute domestic gas supplies for imported foreign oil. This will necessitate a sharp rise in production of natural gas and imports from neighbouring countries [12].

3.1.3. Coal

In view of large indigenous reserves, Pakistan hopes to use coal as an alternative to imported oil. At present coal constitute only 5.4% of Pakistan's primary energy supplies. Total coal reserves of Pakistan are estimated to be around 187 billion tonnes, out of which about 175 billion tonnes are located in Thar Desert in Sindh province. The quality of coal ranges from sub-bituminous to lignite. The Thar coal is low in sulphur and ash content. Historically the coal consumption in Pakistan has come down with increase in gas consumption. There is a great scope for large-scale utilization of coal in power generation. Already, a power plant of 150 MW capacity using Lakhra coal has been completed in Sindh province. The use of coal is also being encouraged in cement industry and has consumed about 20% coal during 2002–2003 [8].

3.1.4. Nuclear power

Nuclear power was introduced in Pakistan in 1971 when a nuclear power plant of 137 MW gross capacity, namely the Karachi Nuclear Power Plant (KANUPP) was commissioned. The plant operated safely for its designed life and generated 10.7 billion kWh of electricity unto December 2002. In January 2004, the plant was reconditioned to extend its life further by 15 years. At present, it is operating at a reduced power level and has generated 37.3 million kWh of electricity during the period January 2004 to March 2004. Pakistan Atomic Energy Commission (PAEC) built its second nuclear power plant at Chashma having a gross capacity of 325 MW. Efforts are underway for the construction of a third nuclear power plant of 325 MW again at Chashma [13].

3.2. Energy economics

According to the year 2003 statistics Pakistan has an annual per capita GDP equivalent to USD 2100 [14]. In contrast to the latter income if one examines the energy prices for the various sectors of use provided in Table 1, a stark picture of the severity of fuel poverty emerges. To further elaborate this point let us compare the fraction of the per capita GDP that will be spent on consuming, say 10,000 kWh of electricity in Pakistan, UK and USA. These figures are respectively, 22, 6 and 3%.

Cost of motoring using petrol at US cents 36 per litre works out to be 3.2 US cents/km. Likewise, cost of diesel fuel is US cents 24.5 L^{-1}. However, diesel engines are not frequently deployed as power plants for automobiles, primarily due to the small engine sizes currently in use. Cost of motoring using Compressed Natural Gas is reported to be 1.4 US cents/km. Engine sizes for automobiles typically range between 0.8 and 1.3 L, with

Table 1
Electricity prices in Pakistan by sector (2005)

Sector	US cents/kWh
Domestic and public	4.55
Industrial	7.73
Commercial	9.09

a median size of 1.0 L. A typical daily journey involves 40 km of travel within most urban areas.

Land prices have shot up quite disproportionately with each square metre costing $270 with construction cost being of a similar order. Thus private, detached housing is now almost beyond reach of most middle-class folks. This has resulted in the development of high-density urbanisation with even large families residing in flatted settlements.

Due to extreme fuel poverty within the Pakistani controlled Kashmir region people resort to felling of trees for fuel usage. As a result, quality walnut wood (locally known as 'Deodar') which otherwise fetches a price of $48/linear metre if exported to the commercial cities within Pakistan is being used up for cooking and raising of hot water during the harsh winter season.

4. Energy security

The economies of all countries, and particularly of the developed countries, are dependent on secure supplies of energy. Energy security means consistent availability of sufficient energy in various forms at affordable prices. These conditions must prevail over the long term if energy is to contribute to sustainable development. Attention to energy security is critical because of the uneven distribution of the fossil fuel resources on which most countries currently rely. The energy supply could become more vulnerable over the near term due to the growing global reliance on imported oil. In addition, although energy security has been adequate for the past 20 years, and has in fact improved, the potential for conflict, sabotage, disruption of trade, and reduction in strategic reserves cannot be dismissed. These potential threats point to the necessity of strengthening global as well as regional and national energy security.

Getting oil and gas from the well to the refinery and from there to the service station involves a complex transportation and storage system. This transportation system has always been a possible weakness of the oil and gas industry, but it has become even more so in the present volatile geopolitical situation. The threats of terrorism have made the equation more complex. Tankers and pipelines are quite vulnerable targets. Pipelines, through which Pakistan's oil and gas flow is also becoming vulnerable—due to their length, they are very difficult to protect. This makes pipelines potential targets for terrorists.

Pakistan is among the most gas dependent economies of the world. Natural gas was first discovered in 1952 at Sui in Balochistan province (Fig. 7) that proved a most significant and largest gas reservoir. After successful exploration and extraction, it was brought to service in 1955. This major discovery at Sui followed a number of medium and small size gas fields in other part of the country. Pakistan has developed integrated infrastructure of transporting, distributing and utilizing natural gas with 8519 km transmission and



Fig. 7. Map of Pakistan showing the location of Sui—the single most potent source of gas supply.

47,423 km of distribution and service lines network developed progressively over the last 50 years [8].

The Sui field produces 28 million cubic meter of gas per day, about 45% of Pakistan's total production. On January 11, 2005 the supply of gas from Sui was completely suspended due to the attacks of local tribal militants on gas supply installations [15]. Following this event gas supply was suspended to the southern and northern regions of Pakistan. The damage inflicted due to the above-mentioned militant attack was of such magnitude that despite it being treated as a national emergency it took over a week for the repair to be completed. It was not an event of sabotage in isolation-the main gas supply pipeline for Lahore, the second largest conurbation within Pakistan, was also damaged. These incidents resulted in a daily loss of almost USD 0.3 million for the country's power generation system. The cost of repairing the damage caused to gas infrastructure has also been reported to be in millions of USD [16,17].

There is a historical catalogue of problems related to the supply of Sui gas to Pakistan's energy grid. These problems are associated with disputes between the Central government and local tribes over the issues of gas royalties and find their roots since the early days of discoveries of gas. The problem is an ongoing issue and a clear solution that could guarantee a secure supply of gas from Sui has yet to be found.

The present situation cannot guarantee secure supplies of energy in future and hence is not sustainable. It is therefore crucial for Pakistan to adopt a diverse energy strategy which not only decreases dependence on vulnerable energy supply channels but one that also explores secure and sustainable energy resources such as renewables.

5. Renewable energy prospects in Pakistan

Renewable energy sources have enormous potential and can meet many times the present world energy demand. They can enhance diversity in energy supply markets, secure long-term sustainable energy supplies, and reduce local and global atmospheric emissions. They can also provide commercially attractive options to meet specific needs for energy services (particularly in developing countries and rural areas), create new employment opportunities, and offer possibilities for local manufacturing of equipment.

Within Pakistan solar power is one of the most promising renewables. It is more predictable than wind energy and less vulnerable to changes in seasonal weather patterns than hydropower. Whereas generation of power from hydro, wind and geothermal sources is limited to sites where these resources exist in sufficient quantities and can be harnessed, solar energy can produce power at the point of demand in both rural and urban areas. Solar PV electricity is an equally significant energy option for developed and developing countries. Because of the cost of transmission lines, difficulty of transporting fuel to remote areas and issues related to security of energy supply in developing countries are increasingly turning to solar energy as a cost-effective way to supply electricity. It is therefore hoped that within Pakistan the usage of solar thermal and PV modules will increase significantly as the demand for electricity spreads.

Pakistan has vast potential for renewable energy development; the three provinces of Pakistan, i.e. NWFP, Balochistan and Sindh provide vast untapped resources for hydropower, wind and solar energy. The geographical location, topography and local climate of the country favour the exploitation of these resources. Pakistan is ideally located in the sunny belt to take advantage of solar energy technologies. This energy source is widely distributed and abundantly available in the country. The province of Balochistan is particularly rich in solar energy having one of the highest values of annual mean sunshine duration. The energy sector is the single largest source of greenhouse gas emissions as detailed in the inventory developed for Pakistan. As such, it is also the sector, which is believed to have the greatest potential for development of mitigation options.

5.1. Wind power

Wind is another source that could be utilized in the medium term in Pakistan. The only wind data available is with the meteorological directorate. This data was recorded at a low height of about 4 m and is not enough to have a true picture regarding the availability of wind energy. So there is a strong need to have a systematic study of wind data at altitudes of 9–36 m particularly in the most promising sites along the costal line and up the mountains. Average wind speed for some selected sites is not enough for wind power generation to be feasible, although the wind speed can still be utilized to run wind mills to pump water for the areas where it is available at short depths up to 36 m.

In Pakistan, since the establishment of the Alternative Energy Development Board in the year 2002 initial contracts were signed in 2004 with the view to establish the first generation wind farms. In this respect, there are presently a total of 16 companies that are supplying wind turbines. From the present average base of 50 MW that has been installed by each of the 16 companies, the plan is to achieve a total installed capacity of 2000 MW by the year 2010.

Table 2
Monthly wind speed, m/s (based on maps presented in Ref. [23])

Month	Karachi	Multan	Quetta	Lahore	Islamabad	Peshawar
January	2.3	1.1	2.3	3.4	1.1	1.1
February	2.3	2.3	3.4	2.3	1.1	2.3
March	3.4	2.3	3.4	3.4	1.1	2.3
April	4.5	2.3	3.4	3.4	1.1	2.3
May	6.8	2.3	3.4	3.4	2.3	2.3
June	6.8	2.3	3.4	4.5	2.3	3.4
July	5.7	3.4	3.4	4.5	1.1	3.4
August	7.9	3.4	3.4	3.4	1.1	3.4
September	4.5	1.1	2.3	3.4	1.1	3.4
October	2.3	1.1	2.3	3.4	1.1	3.4
November	2.3	1.1	2.3	3.4	3.4	2.3
December	2.3	1.1	2.3	3.4	3.4	3.4

Unlike the northern countries of the world where there is a significant potential for producing wind power due to a high annual-average of wind speed, Pakistan's availability factor for wind has been estimated to be only 18–25%. Table 2 provides wind speed data for the major population centres for Pakistan, adjusted to the height of 40 m.

5.2. Solar energy

Evacuated tubes for hot water production are increasingly being marketed by China. The cost of such tubes is \$6/tube. As a rule of thumb SHW systems are being designed by incorporating 26 such tubes for each 175 L of water. The cost of the latter system is \$165.

China has also marketing Silicon PV modules with a quoted efficiency of 14% for a price of \$7/W. However, since January 2005 GE Company of USA is bringing PV modules with a factory gate price of \$3.25/W.

In response to Pakistan's commitment for GHG emission reduction, in the year 2001 the Government of Pakistan set up the Alternative Energy Development Board. The Chair of this Board directly reports to the Prime Minister. The authors had detailed discussions with the senior management of the latter Board whose progress is currently being reported. The Board has plans to exploit renewable energy in a major way. It has therefore set a target of generating 10% of the total electricity demand for Pakistan via renewable energy by the year 2015. The current electrical energy consumption for Pakistan is 17,700 MW with an annual growth in demand of 1000 MW. There are a total of 75,000 villages that are off-grid containing 4 million homes, with each dwelling accommodating around 4–5 people. Most of these off-grid villages are in the North–West Frontier Province and Balochistan states. The Alternative Energy Development Board has set a target of electrifying a thousand villages via solar PV technology by the year 2010. In this respect the first tranche of contracts has been awarded to the Sehgal electronics group (Pakistan).

Micro financing is currently being made available via Khushali Bank for alleviating fuel poverty. Each PV-electrified home will have a 400 W power supply, with overnight storage in the form of lead-acid batteries.

Table 3
Domestic electricity consumption patterns for Pakistan

Month	USD[a]
January	6.7
February	7.6
March	8.7
April	11.8
May	21.8
June	23.6
July	30.9
August	12.7
September	11.3
October	10.2
November	9.1
December	8.2

Price of electricity in Pakistan in US cents/kWh.
[a]1 USD = 60 Pakistan Rupees (January 2005).

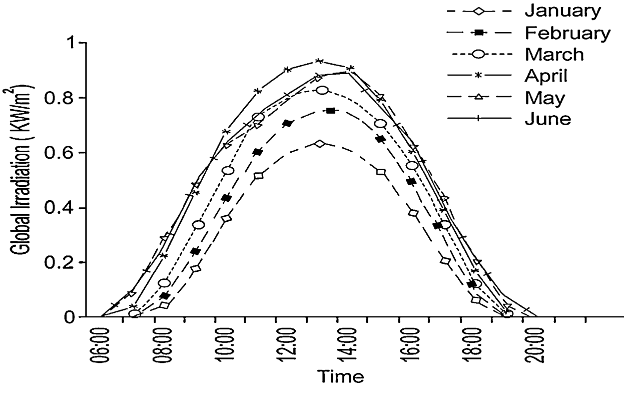


Fig. 8. Monthly-average hourly irradiation for one location (Hyderabad, Sindh) in Pakistan.

There are also plans for local production of PV modules with an expected achievement of production capacity of 3 MW/year. This production capacity is expected to be realised within the next 3 years.

Table 3 presents solar irradiation data for six principal locations within Pakistan. These data were estimated from measurements of long-term records of sunshine duration using validated models [18]. Furthermore, Fig. 8 shows monthly-average hourly irradiation for one location (Hyderabad, Sindh) in Pakistan. Note that in the latter figure the solar energy income has been plotted against local clock time. Close observation of the latter figure and monthly-averaged irradiation presented in Table 3 enables us to come to a reasonable assumption that for 7 months during the year (mid-March to mid-October) the averaged noon irradiance exceeds 800 W/m^2.

5.3. Possible routes for solar PV in Pakistan

In the last two decades, the cost of PV electricity has gone down by a factor of 10, and is expected to reduce further thus creating more potential [19]. Global demand of PV equipment has grown consistently by 20–25% per annum over the past 20 years. It is reported that in 2001 and 2002 global PV shipments were 395 MW and 525 MW, respectively. During 2002, world production of PV increased by a record 43.8% [19]. Solar PV may be exploited in Pakistan via following two routes.

5.3.1. Off-grid or stand-alone sector

Stand-alone systems produce power independently of the utility grid. In some off-the grid locations, as near as one-quarter mile from the power lines, stand-alone PV systems can be more cost effective than extending power lines. They are especially appropriate for remote, environmentally sensitive areas, such as national parks, cabins and remote homes. In rural areas, small stand-alone solar arrays often power farm lighting, fence chargers and solar water pumps, which provide water for livestock. Direct-coupled systems need no electrical storage because they operate only during daylight hours, but most systems rely on battery storage so that energy produced during the day can be used at night. Some systems, called hybrid systems, combine solar power with additional power sources, such as wind or diesel.

5.3.2. Grid-connected sector

Grid-connected PV systems, also called grid interface systems, supply surplus power back through the grid to the utility, and take from the utility grid when the home system's power supply is low. These systems remove the need for battery storage, although arranging for the grid interconnection can be difficult. In some cases, utilities allow net metering, which allows the owner to sell excess power back to the utility.

5.4. Hydel power

Hydropower is one of the main energy sources for Paksitan. From 1960 to 2003, the installed capacity of hydropower generation increased at 48% per annum as shown in Fig. 9 [20]. The share of hydropower generation installed capacity in total electricity

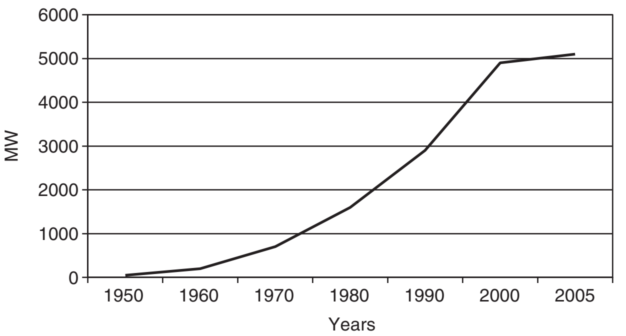


Fig. 9. Growth of hydroelectricity generation installed capacity in Pakistan.

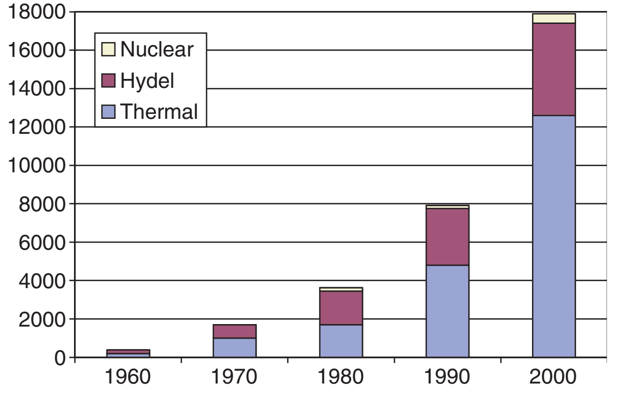


Fig. 10. Growth in installed generating capacity of electricity.

generation mix decreased from 70% in 1960 to 28.3% in 2003 as shown in Fig. 10. The present installed capacity of hydropower generation is 5041 MW [21]. Out of an approximate total hydropower potential of 40 GW only 16% has been developed so far. Further development is slowed down due to long lead-time, political conflicts and high capital cost of the dams [20]. Microhydel is currently exploited at 1000 sites in Pakistan.

6. Prospects for sustainable energy production in Pakistan

Using information presented in Tables 2–4, respectively, on wind speed (corrected for a height of 40 m above sea level) domestic electric consumers and solar energy income, Fig. 11 has been prepared. Note that the wind power is a function of the cube of the wind speed. The demand plot for energy profile is fairly representative of the overall electricity requirements for Pakistan as the industrial sector has a fairly flat profile with the commercial sector being closely aligned with the domestic sectors seasonally adjusted demand. Note that April–August months are the hottest and most humid months with consequential high air conditioning load. Solar energy does provide a responsive means of supply, with doubling of income in summer over winter, although not to the extent of the increase in demand that seems to require a three-to-four-fold summer provision over that needed in winter. Wind energy seems to be a rather poor candidate with only a 20% or less power availability during 8 months (January–April and September–December) of the year. Only during the monsoon period there seems to be any reasonable wind power density available. Furthermore the availability factor for wind is also quite low, with estimates of 0.2–0.25 being quoted by the Alternative Energy Board for Pakistan.

Muneer has presented present cost comparison for solar and wind technologies for Western Europe-those costs provided in US cents/kWh are, respectively, 55 and 5.5 [22]. The annual average wind speeds for Western Europe and Pakistan (southern coastline where maximum wind speeds are expected) are, respectively, 7.5 and 3.75 m/s, and the annual-average daily solar incomes are respectively, 1.8 and 5 kWh/m^2. Thus, on the basis of the above energy density figures the amortized costs for Pakistan may be respectively estimated as (US cents/kWh) 77 and 20 for wind and solar power. The latter source has thus got an economic advantage over the former by a factor of four. Solar energy has also

Table 4
Irradiation values for Pakistan, MJ m^{-2} day [24]

Month	Karachi			Multan			Quetta			Lahore			Islamabad			Peshawar		
	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
January	9.6	17.7	15.3	6.0	15.2	12.2	5.9	17.6	13.2	4.6	14.2	10.5	4.6	14.1	10.1	4.4	15.6	10.5
February	10.0	19.8	16.3	6.9	18.8	14.6	7.4	21.7	16.0	5.7	19.1	13.8	4.4	17.5	13.6	5.3	19.9	14.3
March	11.0	23.7	20.2	8.8	23.2	18.0	9.0	25.1	18.9	7.6	23.4	17.6	5.7	21.9	15.5	5.8	24.8	17.4
April	15.9	25.0	22.2	13.5	26.2	22.5	12.9	29.6	24.2	10.8	26.0	21.6	9.7	27.2	22.0	10.4	28.0	21.5
May	17.0	26.4	23.0	13.9	27.4	23.6	15.0	32.1	27.4	12.4	27.7	23.1	13.0	28.1	24.3	13.2	30.1	24.9
June	14.2	27.4	22.5	13.2	27.1	22.8	21.2	32.0	28.6	12.8	28.0	23.6	13.5	28.0	23.3	16.5	31.2	26.5
July	10.4	25.6	17.5	12.4	26.3	21.6	15.2	29.6	24.9	8.4	26.5	18.9	10.8	27.3	21.1	12.6	28.7	23.2
August	9.8	25.6	16.8	13.5	25.3	21.4	14.8	27.6	24.1	9.4	25.9	19.5	10.1	25.3	20.5	9.1	26.2	20.9
September	11.6	24.6	30.1	14.1	23.2	20.2	17.9	26.1	23.1	11.9	23.7	19.8	13.4	2.1	19.5	3.2	23.4	19.2
October	14.2	21.4	18.9	11.9	19.6	16.7	13.7	22.9	19.7	10.6	19.2	16.0	8.9	18.4	15.7	9.1	19.2	16.0
November	11.5	18.1	15.7	9.6	15.9	14.0	8.6	18.8	15.3	7.2	15.0	12.4	7.8	14.5	11.6	7.0	16.7	16.3
December	8.2	15.8	14.1	5.9	13.6	11.1	0.2	15.2	12.3	4.7	13.1	10.2	3.8	11.7	8.1	4.6	13.1	10.5

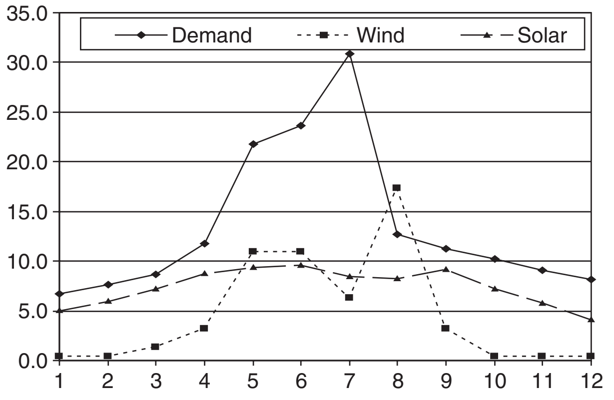


Fig. 11. Monthly electricity demand and, solar and wind supply potential.

got a fairly stable spatial distribution unlike wind that seems to have a favorable power density only along the Balochistan coast. Even for that region, the temporal variations are very large—a clear demerit. Another chief disadvantage regarding wind is related to the security of electricity supply from Balochistan to the rest of Pakistan as pointed out at length in Section 4.

7. Conclusions

Pakistan is an energy deficient country and its present energy supply is lead by fossil fuels. The country relies on import of fossil fuel as its indigenous reserves meet only a small proportion of the total energy demands. The existing oil and gas reserves are projected to phase out in within a period of 12 and 21 years, respectively. The security concerns associated with country's indigenous gas reserves are adding to the complexities of energy needs and supply.

Pakistan has vast renewable energy resources such as solar energy and wind power. Solar and wind energy technologies are at their early stages of exploitation in the country and there are a number of demonstration projects currently under progress.

A comparison of solar and wind energy prospects indicates that the former has clear edge over the latter for a number of reasons. Solar energy is a much economical choice for Pakistan as compared to wind energy-respective costs for solar and wind energy are (US cents/kWh) 20 and 77. Availability of solar energy is quite adequate and responsive to the varying energy demand over the year. Wind energy on the other hand seems to be a poor candidate with only marginal power availability during 8 months (January–April and September–December) of the year. Furthermore the availability factor for wind is also quite low, with estimates of 0.2–0.25 being quoted by the Alternative Energy Board for Pakistan. Solar energy has also got a fairly stable spatial distribution unlike wind that seems to have a favorable power density along the Balochistan coast. Even for that region the temporal variations are very large, with a further complexity of lack of supply securityclear demerits.

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